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Volatile binding media: the first 20 years … and beyond

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In the 20 years since Hans Hangleiter introduced volatile binding media (VBMs) to conservation, their adoption by conservators in all disciplines has been very rapid. This paper is a retrospective review of the published literature about VBMs in conservation during the 20 years between 1995 and 2015. It aims to survey the published literature as thoroughly as possible, in order to describe the development of knowledge in this field. Published sources are analysed by conservation discipline, themes, and country of origin in order to show how knowledge and practice of VBMs have spread. Trends in the research about VBMs are described, with a particular focus on major research developments since 2008 (when a literature review about cyclododecane was published by Rowe and Rozeik). Finally, it offers suggestions for future research directions.

1 Introduction

My interest in volatile binding media (VBMs) was developed when I wrote a literature review about cyclododecane (CDD) with Sophie Rowe (Rowe and Rozeik 2008). We had both previously used CDD in practical treatments (Rowe *et al.* 2010; Rozeik 2009) and wanted to find out more about it – especially the (then) largely unexamined questions about occupational health and safety. Since then, I have retained an interest in CDD – and in other VBMs, such as menthol, that are starting to become popular – and I have continued to collect references that appeared after our review was published.

This paper has four purposes. Firstly, it aims to tell the story of VBMs over the 20 years since their introduction in 1995 by looking at how their use spread though different countries and conservation disciplines. Secondly, it brings our previous literature review up to date by presenting major developments in the conservation literature about VBMs since 2008. It will also discuss recent trends in research and practice relating to the use of VBMs in conservation. Finally, it offers suggestions for future research directions.

2 Survey of the literature on VBMs

The data for this paper comes from a comprehensive survey of the literature about VBMs. The survey includes publications produced between the introduction of VBMs to conservation in 1995 (see Hangleiter *et al.* 1995) and March 2015 (when the conference 'Subliming Surfaces: Volatile Binding Media in Heritage Conservation', at which this paper was presented, was held). It thus covers the first 20 years of VBMs in heritage conservation. Because this survey was carried out before the 'Subliming Surfaces' conference, none of the other papers presented at the conference are included in the data; obviously, their inclusion would significantly alter the number and range of publications, and this should be borne in mind when looking at the results. The benefit of this kind of analysis is that it can show patterns that are not necessarily apparent from just reading relevant articles.

The references surveyed were gathered by searching the two conservation-specific abstract databases (BCIN and AATA), as well as the academic digital library JSTOR[1]. The keywords used were 'cyclododecane', 'menthol', 'tricyclene' and 'camphene', as these are the VBMs that have been most commonly proposed for use in conservation. References were screened to select only those that directly concerned the use of these materials in heritage conservation. Where the applicability of a source was unclear (e.g. if the keywords included 'cyclododecane', but the abstract did not), the source was not included in this survey. Where possible, the original sources were traced in print or online, so that the scope and content of the paper could be verified. In addition, relevant references cited in these papers were followed up, in order to broaden the search, and in case

1 These databases can be found at http://www.bcin.ca, http://aata.getty.edu and https://www.jstor.orgrespectively.

anything had been missed from the abstracting databases. In some cases, this produced references to blogs or newspaper articles that had not been included in the search of the abstract databases (for example, where an author had referenced their own blog post on an institutional website). These references were included in the survey dataset, because they had been cited in the conservation literature. However, no effort was made to trace further references of this kind because of the lack of a comprehensive database or search tool for informal publications such as newspaper articles or blog posts. Any attempt to find these references by e.g. carrying out a web-based search would risk excluding newspaper articles that have not been archived online or blog posts that have been deleted after publication.

After searching in this way, a total of 142 publications were found and entered into a spreadsheet. These were manually categorised by various factors: year of publication; source (the type of publication); country of origin (where the work was carried out); country of publication (where it was published); language of publication; conservation discipline; who carried out the work; the scope of the article (the type of article and what it covers); and finally, the type of VBM (CDD, menthol, tricyclene or camphene).

There are some limitations with this sort of literature survey. The most obvious is that not all work is published in a way that would be captured by this survey – or is even published at all. There are many excellent conservation projects using VBMs that are effectively 'invisible' because they have not been shared in formal publications. Furthermore, it is quite common to find work that is published, but in non-traditional ways (e.g. newspaper articles, blogs, mailing lists, etc). Even conference presentations (which are a way of sharing information with peers) are not formally disseminated through the conservation literature except in the rare instances where proceedings are published. Beneath the top level of easily-discoverable academic literature about VBMs, therefore, there is another layer of informal knowledge-sharing – and beneath that, there is a massive iceberg of practice and knowledge that remains private. The implications of these imbalances will be discussed later in this paper.

Secondly, the survey mostly covers publications that are in the main academic languages (English, German, French, Spanish and Italian). There are publications in other languages, but they are hard to find because those languages are not routinely abstracted. In practice, this is probably not a big limitation, because conservation is a small and relatively international discipline and most research is published in English in order to reach the widest audience.

Finally, academic publication (which forms the majority of this survey) has a strong bias towards certain types of content – with a particular emphasis on novelty. The academic literature covers new developments and knowledge about VBMs, but it does not show everyday usage or prevalence.

Thus, this analysis cannot show precisely how many conservators are using VBMs currently, nor how they are used in routine treatments, but it *can* reveal what some conservators have found sufficiently interesting to share with their peers, in a formal way, in a major language!

3 Results

My questions about the current state of knowledge about VBMs in conservation can be expressed roughly as 'who, where, what, why, when and how': who is writing about VBMs, where do they work, what are they doing with them (and why), and when and how is this work disseminated?

To answer these questions, I will start by discussing the introduction of VBMs to conservation and their subsequent spread (the 'when' question above). I will then look at the implications of language and geography for this spread. The next section examines how VBMs are used in conservation: who is using them? What uses are conservators finding for VBMs, and on what kinds of objects and materials? Finally, I will look at how information about VBMs is disseminated, and discuss a few potential problems with the current situation.

3.1 The introduction and spread of VBMs in conservation

VBMs were first introduced to conservation in 1995 (Hangleiter *et al.* 1995). How did they spread so widely that, only 20 years on, a major conference was held about them? Figure 1 shows the cumula-

tive frequency of publications on VBMs by year[2]. It starts out slowly, rises steadily throughout the late 1990s, and then increases noticeably from about 2004 to 2007; indeed, the year 2007 was a high-water mark for VBMs, with 22 publications (15.5% of the total) (Figure 2). In the five years up to 2015, the number of new publications tails off sharply. This pattern is probably typical for a new subject or material: it takes 5 or 10 years for the word to spread, then it becomes the fashionable thing, and everyone jumps on the bandwagon – then they lose interest and move on to the next big thing. (The existence of these conference proceedings hopefully shows that interest in VBMs will endure, however.)

To break this down further, I looked at the cumulative frequency of publications in each language. The literature about VBMs was exclusively in German until 1999, and even then the English language publications came from German conservators. Perhaps the most influential paper that year was Jägers and Jägers' summary of volatile binding media at the British Museum conference 'Reversibility: Does it Exist?' (Jägers and Jägers 1999). This brought VBMs to a wider, English-speaking audience, and the following few years saw several publications from the US. From the early 2000s, publications appeared in French, Italian, Spanish and Chinese. By 2005, the number of publications in German was outweighed by those in English, and English has remained the primary language of publications about VBMs ever since (Figure 3). English is the dominant language of academic literature, so this is unsurprising: but it is striking that, even now, half of the literature is in other languages (with a quarter being in German).

I also recorded the place of origin for each publication – that is, the country where the authors are based or where the work was carried out, rather than the place that the work was published. Thus, an article describing the conservation of 100 clay print librettos from the Hong Kong Heritage Museum that was published in the Journal of the American Institute for Conservation (JAIC) (Tang and Lai 2009) was classified as 'China', rather than 'United States'[3]. This distinction allows a clearer picture of where VBMs are actually being used worldwide – something that is especially important given their use on archaeological sites.

The first publication about VBMs in conservation came from Germany in 1995 – and there were only German publications in 1996, 1997 and 1998. In 1999, the first of several articles in JAIC appeared, and its use spread quickly throughout Europe, North America and Australia thereafter. By 2015, VBM use had been reported in 19 countries (Figure 4 and Table 1). (The papers and posters presented at the 'Subliming Surfaces' conference in 2015 have since added another 3 countries, with work being reported from the Czech Republic (Boumová *et al.* 2018), Tanzania (Peters and Ohara Anderson 2018) and India (Bonnat 2018).) As noted earlier, this survey underrepresents work that is not published in the major European languages, or that is not published at all. It is probably safe to say that, nowadays, VBMs are used in every country where conservators work, and not just those shown in Figure 4.

3.2 Who uses VBMs in conservation, and how?

The survey data can also be used to show who is using or writing about VBMs – for example, students, practising conservators, scientists, and so on. A significant portion of the literature (13.4%) comprises Masters theses by conservation students (e.g. Lee 2004; Confer 2006; Aalto 2010). In addition, some of the research later disseminated through journals and at conferences originated as student projects (e.g. Cleere 2005; Wallon 2008; Rozeik 2009), and a further – but unknown – proportion will have come from authors whose first experience of VBMs came during their primary conservation training. It is clear therefore that students continue to be important contributors to research about VBMs; indeed, three of the poster abstracts in this volume (Peters *et al.* 2018; Peters and Ohara Anderson 2018; Langdon *et al.* 2018) present research carried out by current students. This is unsurprising: students tend to have access to analytical equipment, lots of time to focus on research and often a strong desire to try out novel materials and techniques. Although the large numbers of student conservators researching VBMs is welcome, there are some

2 Conference presentations that were subsequently published have been categorised by the year of presentation rather than the year of publication, where this differs.

3 Hong Kong is included with China for the purposes of this analysis, as the only relevant publication appeared after Hong Kong had been transferred from the UK to China in 1997.

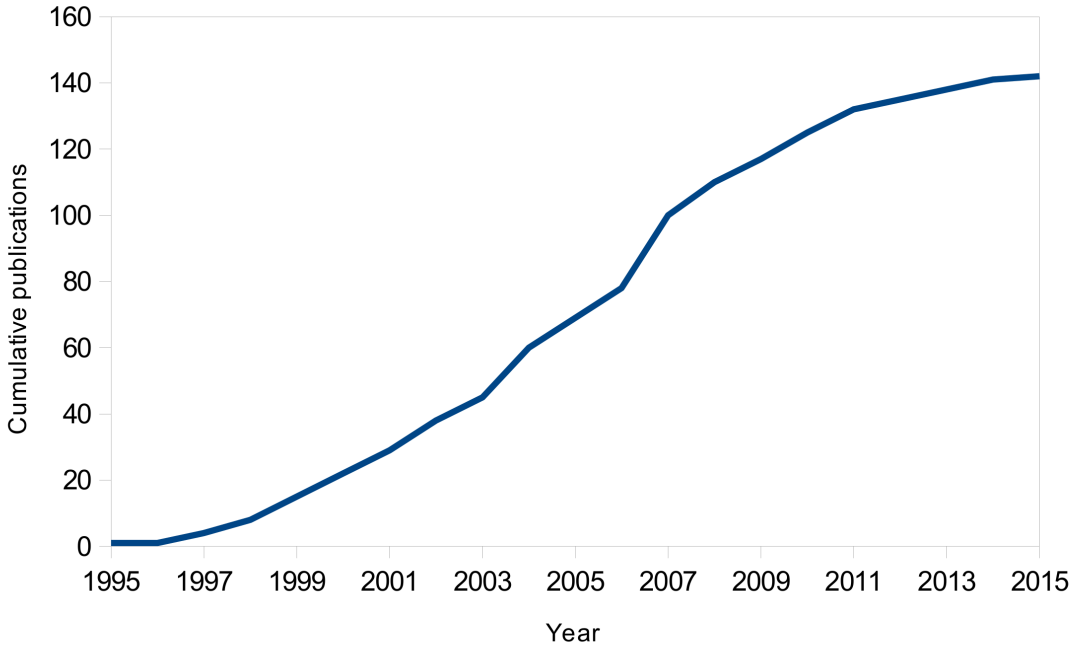

Figure 1 Cumulative publications over time.

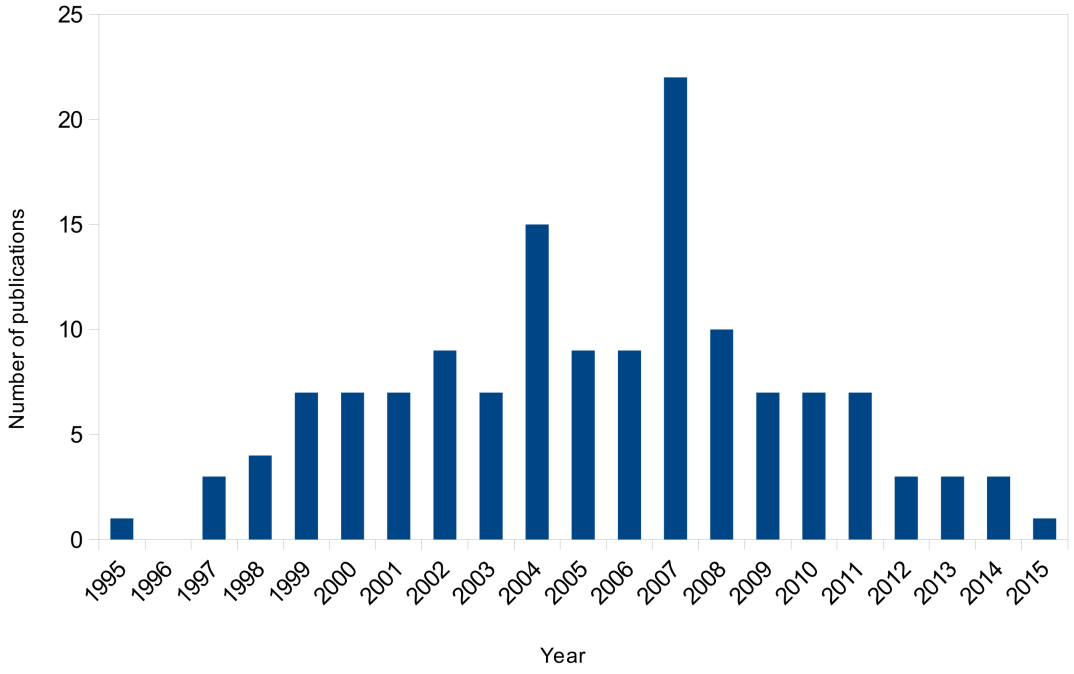

Figure 2 Number of publications per year, 1995–March 2015. Nearly half of the publications in this survey (45.8%) were published in the five years 2004–2008.

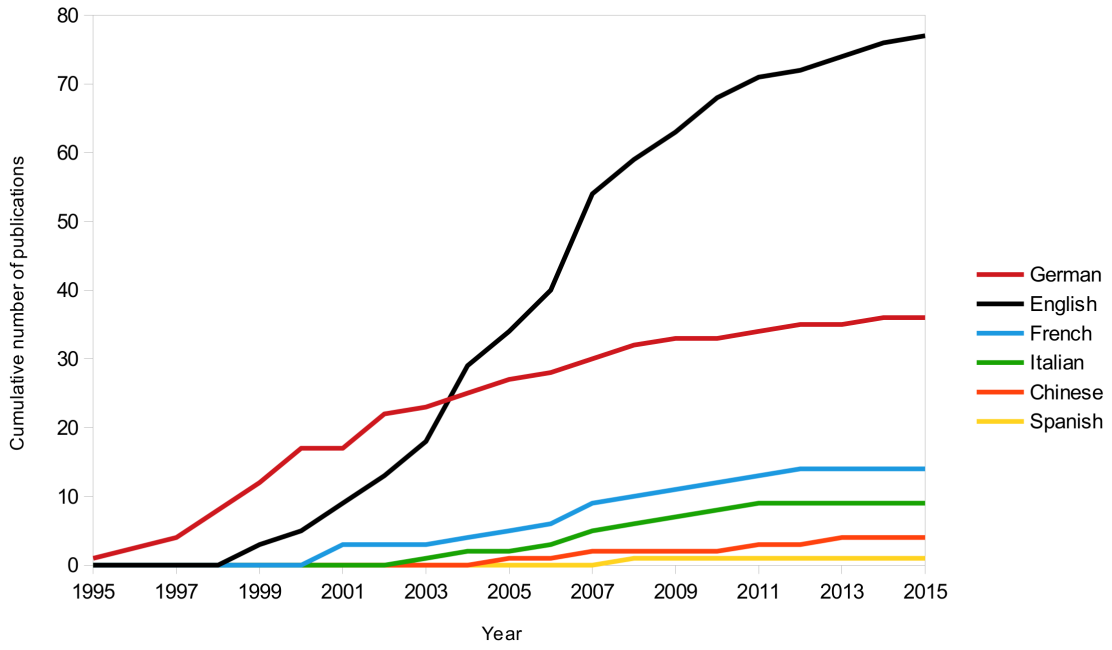

Figure 3 Cumulative frequency of source language.

caveats: student research studies are not always well designed or executed, and it can be hard for readers to obtain copies of work that has only been published in a Masters degree thesis and then deposited in a single University library – or even to discover its very existence. It would be beneficial for the development of knowledge in this area, therefore, if students carrying out research into VBMs would consider writing up that research for wider audiences, especially in peer-reviewed publications where it will be included in one of the conservation-specific abstract databases.

It is harder to discern who the other users of VBMs are. It is clear from the dominance of case studies that their numbers include a large number of conservators carrying out practical work on objects. Every type of occupational context is represented, including private practice, universities, museums both large and small, archaeological excavations and work in situ (e.g. in churches or at other sites). Following the literature review by Rowe and Rozeik (2008), these case studies describe VBMs being used as a hydrophobic mask, as a temporary support or means of immobilisation, as a release layer, as a temporary consolidant during intervention, or as temporary adhesive. The papers published since the literature review all fall into one of these categories, with no fundamentally new uses being proposed since 2008.

A smaller proportion of papers (approximately 10%) concerns the properties and behaviour of VBMs (e.g. their sublimation rates or types of crystallisation on different substrates). Although this research is sometimes carried out by conservation scientists, the focus is usually very practical (e.g. understanding how to modify the behaviour of VBMs to optimise treatment outcomes, or gaining a deeper knowledge of how they interact with objects and materials). The question of whether these materials leave residues after sublimation continues to be debated, and has not yet reached a satisfactory resolution.

An alternative way to find out who is using VBMs is to look at what kinds of material or object are involved. The publications in this survey were classified by discipline, using multiple categories for a single paper where necessary. The categories used broadly follow those used by the UK's Institute of Conservation (Icon) for its material-specific membership groups (thus, archaeology, metals, and ceramics and glass are categorised separately from all other objects). Papers that are about all aspects of VBMs, or that focus exclusively on their technical properties, are classified as 'general'.

Excluding general articles, the most significant distinct disciplines, making up half of the references, are paper, stone and wall paintings, and archaeology (Figure 5). Apart from one paper

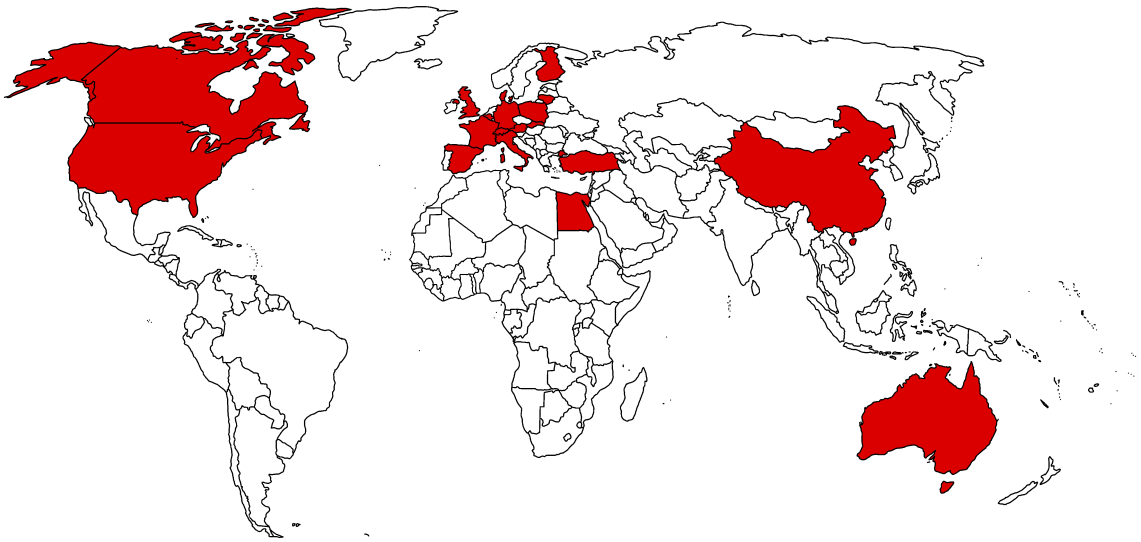

Figure 4 The 19 countries where VBMs were reported to have been used by March 2015.

Country of origin	Year of first publication	Total publications 1995–2015
Germany	1995	37
US	1999	29
France	2001	13
Australia	2002	1
Austria	2002	3
Denmark	2003	3
Italy	2003	13
Belgium	2004	1
Canada	2004	6
Slovak Republic	2004	2
Turkey	2004	6
UK	2005	7
China (including Hong Kong)	2007	9
Egypt	2007	1
Spain	2007	3
Switzerland	2007	6
Lithuania	2008	1
Poland	2009	1
Finland	2010	1
	TOTAL	**142**

Note: the number of publications in the table totals 143, because one paper (Blümich *et al.* 2010) was authored jointly by researchers from German and Italian institutions. There are, however, 142 unique publications in this survey.

Table 1 The first year where VBMs were reported to have been used in each country, and the total number of publications from that country (up until March 2015).

on ivory (Lee 2004), and one on leather (Lavoie 2006), there have been no other papers dealing specifically with the use of VBMs on organic materials other than paper or textiles. Conservators seem particularly reluctant to use use VBMs on ethnographic objects, with most of the object conservation literature concentrating on stone, metals, ceramics and glass.

Figure 6 shows the cumulative frequencies over time for these disciplines. The two largest disciplines (stone and wall paintings, and paper) are represented from the earliest time, with a particularly large surge for the former in 2007 and 2008. Papers about archaeology only started to become popular in the mid-2000s, and the same is true of objects conservation. Before then, paintings conservation was a more popular area for study, but it tailed off quickly and is now relatively under-represented. All five papers that specifically concern metal objects were published between 2000 and 2003, and there have been no publications on this subject since.

Most of the disciplines shown in Figure 6 indicate a general tailing off of interest in VBMs over the last five years. The exception is the 'general' category, which shows an upward trend. This growth represents the only two papers that deal specifically with health and safety issues (Vernez *et al.* 2011a,b), as well as more recent research about the use of CDD to aid scientific analysis.

4 Trends in VBM research

The survey data revealed several broad trends in how VBMs are being used. The earliest papers tended to be exploratory and very practical: you can almost see the authors experimenting empirically after discovering these marvellous materials, and trying to find out what they can do.

The first seven or eight years also saw a large number of papers devoted to the properties and behaviour of VBMs: looking at the sublimation rate, for example, or discovering how to modify penetration and film formation. This type of research decreased in the mid-2000s, but has recently returned, with investigation into the vexed question of residues being very popular. Also popular is the issue of crystal formation inside porous substrates, and more generally the behaviour of VBMs on different substrates. Authors are now using more sophisticated methods of imaging to study VBMs and gain a more precise understanding of their properties and behaviour.

From about 2000, there are large numbers of practical case studies published, as these materials started being used more widely, and outside Germany. It is around this time that CDD became the dominant VBM, involved in the vast majority of studies in this survey (over 90%). At the same time, new uses for CDD were being proposed at a great rate, with the peak being from about 2000 to 2008. This has diminished as CDD becomes more widely used as a conservation material.

Many of these case studies were disseminated informally, through blogs, newspaper articles, and other public outlets, either as a primary means of publication, or in addition to more formal routes[4]. It is interesting to speculate why CDD is found so frequently in this kind of informal publication. I suspect that it is felt to be interesting to non-specialists in a way that, say, B72 or Klucel G are not, because its ability to reverse through sublimation gives it almost magical-seeming properties.

This has implications for knowledge-sharing. When writing this paper, I went back and checked all the online references that Sophie and I had included in our review paper (Rowe and Rozeik 2008), and most of them were no longer available. Web pages are a good way of reaching a wider, non-specialist audience, but not so good for sharing professional knowledge, even in the fairly short term.

4.1 Scientific analysis

The next trend is a rather recent one: the application of scientific analysis to the study of VBMs in conservation. Of course, there has been analysis of VBMs since the start, but in the last 5–7 years that research has been carried out by non-conservators as well as conservators. Much of it has been published outside the specialist conservation literature – for example, in journals devoted to chemistry, archaeology, palaeontology or occupational health (Vernez *et al.* 2011b). This is a positive trend and reflects perhaps three things: the increased focus recently on

4 As noted above, the majority of these informal publications are not included in this survey of the literature, but I am aware of them through my own web searches for information about cyclododecane in conservation.

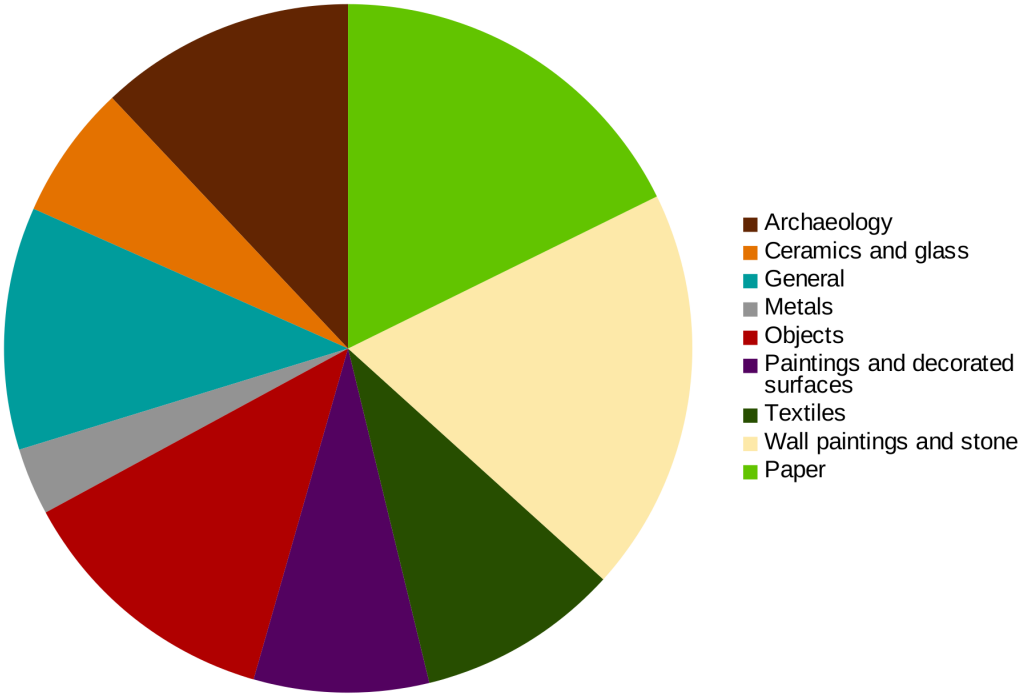

Figure 5 Total publications about VBMs, 1995–March 2015, consolidated by conservation discipline.

studying the properties of VBMs more scientifically (e.g. modelling sublimation rates of CDD accurately rather than just observing its working properties in practice); greater numbers of conservation and other scientists working in conservation and collaborating with conservators (which allows types of analytical research that are not normally accessible to conservators); and also a desire to include conservation research in the body of more mainstream scientific research rather than just burying it in a (relatively) obscure conservation journal.

In the last five years, a completely new use of VBMs (and in particular CDD) has emerged – namely, its adoption by conservation and heritage scientists to aid analytical work. Martin de Fonjaudran *et al.* (2008) describe how cyclododecane can be used as a pre-treatment for wall painting cross-sections that are investigated with FTIR. In a later paper, Prati *et al.* (2013) conclude that the roughness of the cut cross-section (the sample cannot be polished because the CDD is too soft and would smear over the surface) leads to decreased signal intensities, but that CDD provides an effective separating layer for the embedding resin, and that it can reveal diagnostic combination and overtone bands in spectra.

A further use of CDD as an aid to analysis was described by (Jackson *et al.* 2015) at the 'Subliming Surfaces' conference (see also Bowen *et al.* 2015). Their research suggested that CDD can be used as a contrast enhancer for terahertz imaging of wall paintings, because it fills air gaps in the substrate, approximating the refractive index of the plaster and reducing scattering.

4.2 Health and safety

A welcome addition to the literature has been the first publications to examine the effect of cyclododecane on occupational health (Vernez *et al.* 2011a,b). There have been no permissible exposure limits defined for CDD (or other VBMs) as they are used in conservation and, until this study, it was not even known what the exposure would be for a conservator using these materials in typical circumstances. Vernez et al. measured the maximum local air concentration for a number of different treatment scenarios, including indoor and outdoor application, with and without local extraction, and using a brush or a spray to apply the CDD. They found that working under local extraction drastically reduced exposure to CDD, and that outdoor concentrations were greater than indoor ones, with the highest levels when spraying CDD outside but in a confined space.

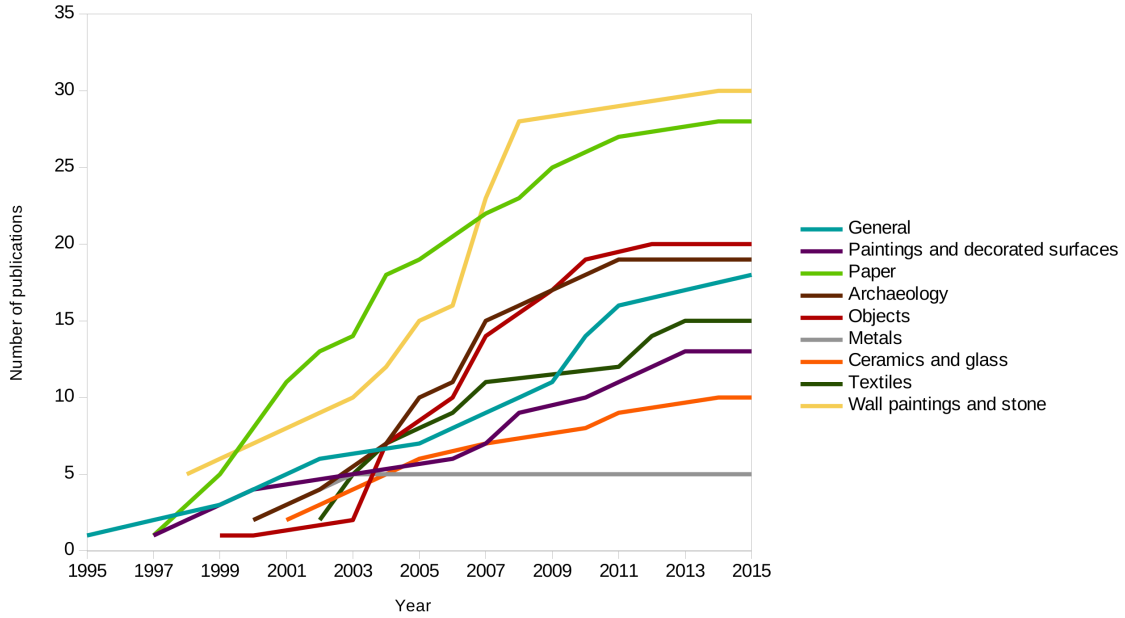

Figure 6 Cumulative frequency of publications about VBMs, 1995–March 2015, sorted by conservation discipline.

A deeper understanding of the health and safety issues surrounding VBMs in conservation is particularly welcome, given research by Kingery-Schwartz *et al.* (2017) showing widespread confusion among conservators on this topic. They used CDD as a case study to examine how conservators make health and safety decisions when using innovative materials – and in particular, how they negotiate situations where there is little or no information to inform those decisions. Their research has been driven by the realisation that it is sometimes assumed (e.g. Adlem 2018) that CDD is safe in the absence of evidence to the contrary; Kerith Koss Schrager and her colleagues argue that, until proved definitively to be safe, it should be assumed to be not safe (Koss Schrager 2017). As a result of their research, they hope 'to get the American Conference of Governmental Industrial Hygienists (ACGIH), the body that recommends airborne concentrations of agents and exposure conditions, to define health and safety data for cyclododecane' (Kingery-Schwartz *et al.* 2017: 14). It is hoped that this will build upon Vernez's data about actual exposure levels in practice, to move towards defining permissible exposure limits for conservators using CDD.

4.3 Alternatives to CDD

The final trend is towards a reinvestigation of VBMs other than cyclododecane. For the last 15 years, CDD has become ubiquitous and other VBMs like camphene and tricyclene have been forgotten about. As the novelty has worn off CDD and some of its limitations (such as lengthy sublimation time) have become more apparent, conservators are starting to re-evaluate other VBMs – and in particular, menthol (Rowe 2018).

5 The next 20 years

So where will VBMs go in the *next* 20 years? What are the questions that have not yet been answered? Firstly, I expect to see a more nuanced understanding of how VBMs interact with substrates and other materials used in conservation. There have been a few recent case studies that describe CDD acting as a solvent for other materials. As noted above, the use of VBMs on ethnographic objects is absent from the literature, possibly because of concerns about potential interactions with the materials and components involved. Further research to investigate the compatibility of VBMs with organic materials, and their potential in the treatment of these materials, would be very beneficial.

As a corollary, I expect to see more papers and case studies about *not* using VBMs – cases where it has been ruled out because of its behaviour or properties (e.g. Miller *et al.* 2018). A material could be said to have finally 'arrived' in conservation when it starts to be viewed more sceptically, rather than as

a miraculous panacea.

Secondly, I think that case studies using VBMs will continue to appear in the conservation literature, but in a more low-key way. I expect fewer case studies that describe distinctly new uses of VBMs, and more that just use it routinely as part of a treatment – after all, using cyclododecane in a treatment does not in itself make for an interesting paper any more. Again, this is a sign of maturity for a new material, when it has become a familiar part of the conservation 'repertoire' like Paraloid B72 or Klucel G. Arguably, CDD (if not the other VBMs) has already reached that stage.

With increased use of VBMs in routine practice, I expect to see more treatment reviews in the literature. As CDD has been used for 20 years now, there are more conservators who have had experience of large-scale or long-term use, which provides an excellent opportunity to look retrospectively at how well these treatments have lasted. This sort of review is represented in the current volume (Skinner and Kariye 2018; Tissier 2018; Hackett 2018), and I hope that we will see more over the next 20 years.

Given the increased scientific analysis and collaboration identified in section 4, I expect a greater focus on health, safety and environmental issues. This would also be a natural consequence of increasingly strict chemical and environmental legislation. In particular, the environmental impact of VBMs has barely been studied (with the exception of Kalberer 2015), but this will surely become a more pressing issue in the future, especially given the increased volumes of VBMs used in conservation and their inherently volatile nature.

Finally, I predict that there will be more research into VBMs other than CDD, including a look again at some of the 'technical mixtures' that have already been described in the literature. Menthol is increasing in popularity, and conservators are beginning to understand better its advantages and disadvantages as an alternative to CDD, especially when used in the field (e.g. Skinner and Kariye 2018; Langdon *et al.* 2018). I hope that research will continue into finding other alternatives to CDD (see Rowe 2018 for a summary of this literature).

The trends identified in section 4, together with the possible future directions for research suggested in this section, have been summarised in Figure 7.

6 Conclusion

In the 20 years since VBMs were introduced to conservation, their adoption by conservators of all disciplines and countries has been very rapid. An intense period of experimentation showed them to be a versatile addition to the conservation repertoire, particularly for conservators working on paper, stone and wall paintings or archaeological objects and sites. Much of this knowledge has been driven by student research projects, and these remain an important source of information about the properties and behaviour of VBMs.

Recent trends suggest a turn away from practical case studies and towards other areas, such as health and safety, and scientific analysis. Although CDD has been overwhelmingly the most popular VBM, alternatives such as menthol are also starting to receive more attention.

There remain some areas where research has been scanty or non-existent. The interactions between VBMs and other materials are still not fully understood, and the question of whether residues are left following sublimation is still debated. Issues of health and safety are only now starting to be examined in detail, and there is not yet clear guidance about exposure limits (and the consequences of exposure) for conservators who use these chemicals. The impact of VBMs in the environment is another area where little has been published.

The first 20 years have shown VBMs to be invaluable materials for conservators, and it is expected that the next 20 years will bring even more innovative and useful additions to the conservation literature on this subject.

Biography

Christina Rozeik read English Literature and Philosophy at the University of Cambridge, and then trained as an objects conservator at the Institute of Archaeology, University College London. She has worked at the Fitzwilliam Museum, the Polar Museum, the Whipple Museum and the Museum of Archaeology and Anthropology, all in Cambridge, as well as at the Faraday Museum in London. In 2006–8, she was the founding editor of IIC's *News in Conservation*, and she has also been Editor of the *Journal of the Institute of Conservation*. Christina has a particular interest in communication and professional development issues relating to conservation. Since 2017, she has co-hosted the conservation podcast *The C Word*.

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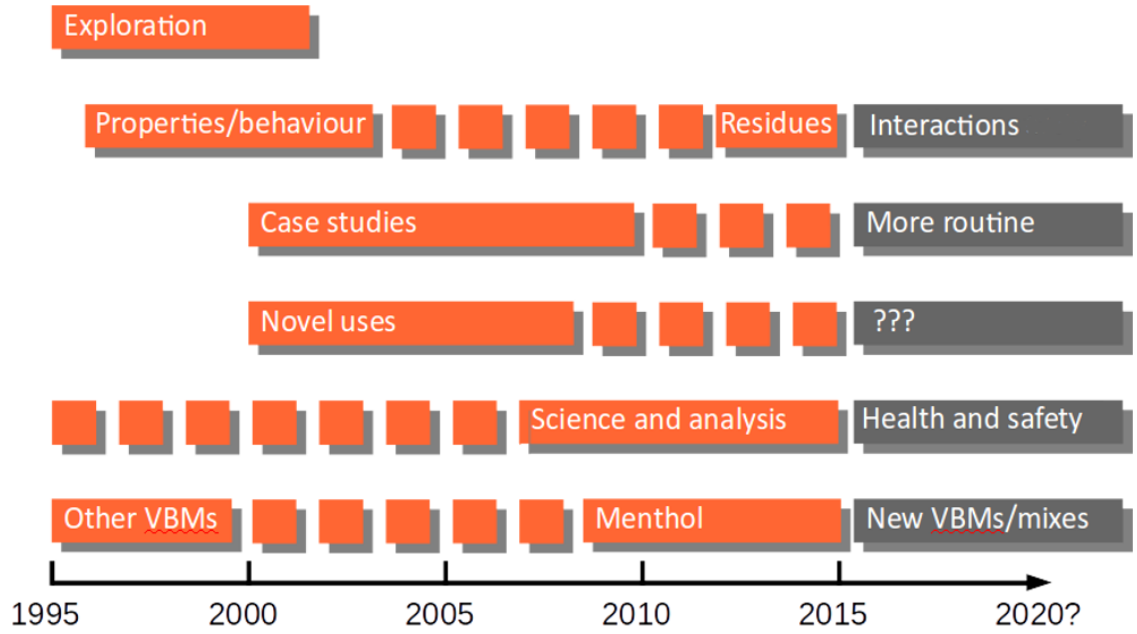

Figure 7 Past and current trends in VBM research in conservation (shown in orange), followed by suggestions for future research directions (shown in grey). Periods of most intense activity are shown as solid bars.

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